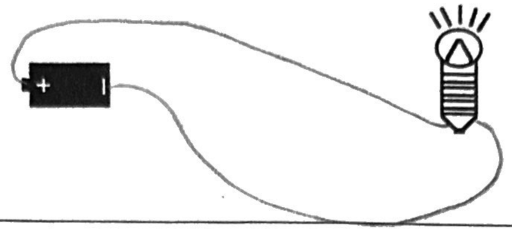
+10 Shelby Cerise
Taylor Larcchea

5.2 Experimental apparatus and techniques

Next we will observe the effects of electric currents in circuits containing light bulbs and batteries. These are the simplest examples of systems in which we can observe the fundamental electric and magnetic properties of continuous electric currents.

❑ Using one battery, some clip leads (the insulated wires with clips on the ends, not the bare nichrome wire), and a round bulb (#14) *but no socket*, make the bulb light up. If the bulb glows with a steady light, this is a "steady state."

Sketch your "circuit," showing how you connected the wires.

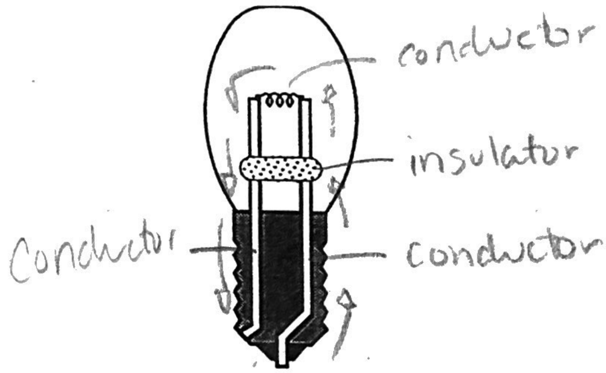


5.2a ☆

5.2.1 Light bulbs

❑ Examine a light bulb carefully, and imagine slicing the bulb in half lengthwise. A cutaway sketch is shown below.

On the sketch, label the important parts and connections, indicating which parts of the bulb you think are metal conductors, and which parts are insulators. Using a different color if available, show the conducting path that electric current would follow through the bulb.



5.2.1a

The filament (the very thin metal wire that glows) is made of tungsten, a metal that does not melt until reaching a very high temperature. A glowing tungsten wire would rapidly oxidize and burn up in air, so there is a vacuum or an inert gas such as argon inside the bulb.

Heating the filament: It is easy to shift the electron sea through the copper wires, but the thin tungsten filament in the bulb strongly resists the passage of electrons. When the electron sea is forced through the tungsten, the electrons collide with the positive cores (nuclei plus inner electrons), and this "friction" makes the metal get hot and glow.

❑ **Closely examine the long #48 bulb and the round #14 bulb. The tungsten filaments in both bulbs are about the same length, but perhaps you can see even with the naked eye that the filament in the long bulb is extremely thin -- thinner than the filament in the round bulb.**

Through which bulb would you guess it would be easier to push electric current, through a thin filament (as in the long bulb) or through a thick filament (as in the round bulb)? Why? (At this point this is mostly just a guess, but we'll study this in detail later.)

[illegible] because [illegible] would be less [illegible] to [illegible] into.

5.2.1b

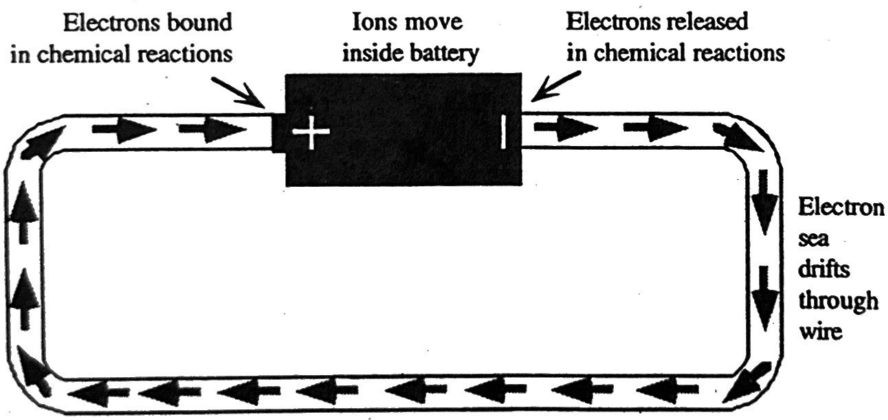
5.2.2 Batteries

As in earlier parts of this book, remember that text with a double vertical bar along the side, such as the following paragraph, indicates that we are stating results without full justification.

> **Batteries:** Chemical reactions inside a battery can release electrons at the end of the battery marked "-". Other reactions bind electrons arriving at the "+" end. Ions move between the ends to restore the end charges. The effect is to move negative charge from the end marked "+" through the battery to the end marked "-". Although it is ions rather than electrons that move *inside* the battery, from the outside a battery acts as though it were an electron pump.
>
> If there is a complete round-trip path (a "circuit") of wires to conduct electrons from the "-" end of the battery around to the "+" end, the battery can keep shifting the electron sea inside the wires around and around the circuit until the battery's store of chemicals and chemical energy is used up.

+
e
−

Here is a simplified picture of a circuit made up of a battery and a length of metal wire. The arrows represent the drift velocity of the electron sea at various locations around the circuit. Every second, some electrons leave the "-" end of the battery, and during the same second *other* electrons enter the "+" end of the battery.



If some charges are moving, but the drift velocities and deposits of excess charge everywhere in the circuit are steady (not changing with time), we call this situation a "steady state." The steady state is *NOT* the same as static equilibrium.

Definitions of static equilibrium and steady state

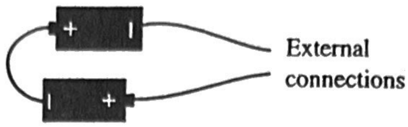
"Static equilibrium" means that no charges are moving.

"Steady state" means that some charges are moving, but their velocities at any location aren't changing, and there isn't any change in the deposits of excess charge anywhere.

To be perfectly correct, a circuit containing a battery and a light bulb is not really in a steady state, because after many hours the battery is exhausted and the current stops. But during the first few hours it is an excellent approximation to speak of a "steady state."

5.2.3 Two batteries versus one battery

Often in experiments it is useful to use two batteries "in series" (one after the other), which makes a stronger pump. To connect two batteries in series, put them in the battery holder, and connect them as shown (note that "+" is connected to "-"):



❑ **Two batteries vs. one:** Connect a round bulb *in a socket* to two batteries in series, using clip leads.

Compare the brightness of the bulb with one battery and with two batteries in series:

The brightness is much brighter with 2 batteries

5.2.3a

Because of this difference we'll usually use two batteries in series in our experiments.

WARNING

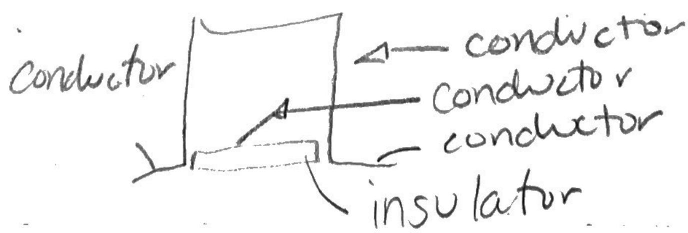
A circuit made up just of batteries and your "clip leads" will use up the battery in a few hours. Such a circuit is called a "short circuit" and must be avoided when you store the batteries.

Your clip leads offer little resistance to the flow of electrons, and if there is a short circuit a large amount of charge will flow through the batteries every second. For every electron that leaves and enters the battery, a molecule in the battery must give up an electron and a different molecule pick up an electron. This process uses up the chemicals in the battery.

5.2.4 Sockets

❑ Examine a bulb *socket* (the receptacle into which a bulb is screwed), and imagine slicing the socket in half lengthwise.

Make a very rough cutaway sketch, and label the important parts and connections. Indicate which parts are metal conductors and which parts are insulators. Trace the path (in a different color if available) that electrons would move through the socket when there is a bulb in it.



5.2.4a ☆

5.2.5 Detecting currents by their magnetic effects

A glowing bulb is an indication that a current of electrons is flowing through the filament. In addition to producing light and heat, electric currents have "magnetic" effects.

Magnetic effects of currents: A current of moving electrons in a wire creates a "magnetic field" encircling the wire that can affect a nearby magnet, such as the magnetized needle in a compass. This *magnetic* interaction is different from *electric* interactions. There is hardly any observable *electric* interaction of the current-carrying wire with nearby materials, because the wires have no net charge (actually, we'll see later that there are tiny amounts of excess charge on the surface, but too little to observe easily).

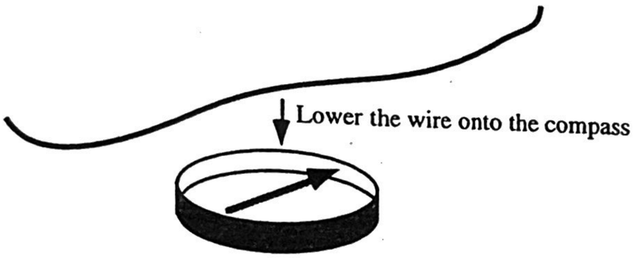
☐ Make a two-battery circuit with a round bulb in a socket. Place your magnetic compass on a flat surface under one of the wires. If you are working on a steel table, you may need to put the compass on a thick book. Also, keep the compass away from the steel-jacketed batteries. (For flexibility in placement, you may find it useful to make a long wire by connecting two of your wires together.) With the bulb glowing, do the following:

① Lift the wire up above the compass.

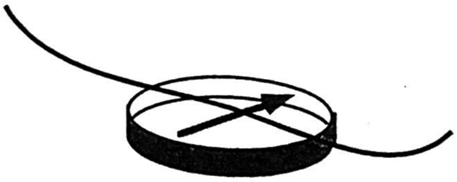
② Orient the wire to be horizontal and lined up with the compass needle. (Using a long wire may make it easier to do this.)

③ Bring the aligned wire down onto the compass.

☐ Observe the effect of the electric current on the compass needle as you bring the wire down on top of the compass.



☐ Also observe what happens when the wire is aligned perpendicular instead of parallel to the needle.



Which orientation produces a deflection of the needle?

Having the wire over the needle produces a deflection

5.2.5a

☐ **Reverse the connections to the batteries, or reverse the direction of the wire over the compass, in order to force electrons through the circuit in the opposite direction. Again make the compass needle deflect.**

How is the deflection of the compass needle affected by changing the direction of the current?

when positive, the needle moves ccw, when negative the needle moves cw

5.2.5b

Note that this is very different from the *electric* interactions you studied with invisible tape, where reversing how you held the tape certainly didn't change its effects on other tapes.

❑ Disconnect the batteries, so that there is no current in the wires.

When you bring the wire down on the compass, is there a deflection?

Without an electric field, there is no magnetic field.

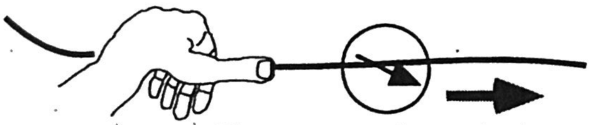
5.2.5c

This checks that it isn't the copper wire itself that is affecting the compass. There has to be a current running in the wire.

We're going to be using the compass to detect the presence of current in a wire, and also to determine which direction electrons are flowing in a wire. You've seen that the direction of the swing of the compass needle depends on the direction of the electron current. We will explain a "left-hand" rule for determining the direction of the electron current.

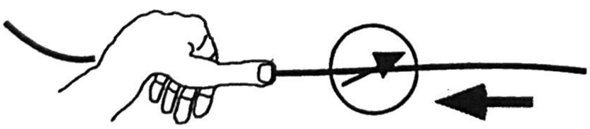
The left-hand rule

Grasp the wire with your left hand. Let your fingers lightly curl underneath your hand so that your fingertips are horizontal (parallel to the desk top). Note that your palm faces downward. With the wire raised above the compass, align the wire and your thumb with the compass needle. Then move the wire down on top of the compass, causing the needle to deflect. If your thumb happens to be pointing in the direction that the electrons are flowing, the colored or pointed end of the compass needle will deflect in the direction your fingertips are pointing. (The colored or pointed end of the needle is the north-seeking pole of the needle.) Here is a top view, looking down on the desk top:



Electron current flow to the right, in direction of thumb
(needle deflected in direction that fingers are pointing)

But if the colored or pointed end of the needle swings in the other direction, opposite to the direction your fingertips are pointing, the electron current runs in the opposite direction to your thumb:



Electron current flow to the left, opposite to thumb
(needle deflected opposite to direction that fingers are pointing)

Experiment with this left-hand rule until you are comfortable with it. You and your partners should pose questions for each other and check each other's use of the rule.

❑ For example, test for electrons emerging from the "-" end of the battery (but stay as far away as possible from the steel-jacketed batteries, perhaps by using a long wire made by connecting two wires together). Connect your batteries to a round bulb.

Using the left hand rule, do you indeed find that electrons flow out of the negative end of the battery? What about the direction of flow at the "+" end of the battery?

> [illegible] end would actually have [illegible] flow and the positive
>
> 5.2.5d

At the end of this chapter we will look a bit more at the properties of compasses and of the magnetic field that encircles a wire. We will study magnetic fields in detail later (Chapters 11 and 12). For now it is sufficient to know that the compass deflection gives us the direction of the electron current in a wire, and the deflection angle is an indication of the amount of current.

5.3 Amount of current in different simple circuits

Using a magnetic compass to measure the amount of current flowing through a wire, we can now make comparisons of the amount of current in several different simple circuits.

5.3.1 Round bulb versus long bulb

- [ ] Screw a round bulb into a socket and make it light up, using two batteries in series. Also try a long bulb. If you're not sure you see a difference in brightness, use two sockets and two sets of wires so that you can quickly change between the two kinds of bulbs, which makes it easier to compare.

What difference do you see in the brightness of the round bulb and the long bulb? In addition to noting the brightness, also note the compass deflection (in degrees) under a wire leading to the bulb. Instead of bringing the wire down onto the compass, you may prefer to break the circuit, place the wire on the compass (aligned with the compass needle), then connect the circuit without moving anything.

	brightness	compass deflection (degrees)
round bulb:	stronger	20°
long bulb:	weaker	20°

5.3.1a ☆

We'll see later that the *force* on electrons flowing through *one* round bulb or *one* long bulb is the same, and the electron *drift speed* is the same. Each electron that flows through a bulb contributes (through "friction") to heating the filament, making it glow.

Given the amount of light emitted and the compass deflection, which bulb has more electrons flowing through it per second? Does this make sense in terms of the thickness of the filaments of the two bulbs? (Compare with your guess on page 171.)

> the amount of light and deflection makes sense. Round bulb's filament allows more electrons through
>
> 5.3.1b ☆

5.3.2 Length of connecting wires

❑ Use two batteries and light one long bulb. Vary the number of clip leads connecting the long bulb to the batteries, and twist the wires into various configurations (use clip leads, not the bare nichrome wire). You might borrow additional clip leads from another group.

How does the length and bending of the copper wires affect the brightness of the long bulb, and the compass deflection under a wire?

effect of wire length and bending on brightness: does not effect brightness or deflection
effect of wire length and bending on compass deflection: does not affect brightness or deflection
5.3.2a ☆

This is very mysterious. It would be reasonable to think that it is charges in or on the battery that produce the electric field inside the bulb filament that drives electrons through the bulb. Yet when we move the bulb farther away from those charges in or on the battery, or change the bulb's orientation, or bend the wires, there is hardly any change in the brightness of the bulb or the compass deflection due to current in a wire.

5.3.3 Short circuit

A "short" circuit consists only of a battery and wires (or other very good conductors). There is no bulb or nichrome wire in the circuit.

❑ Connect a clip lead *briefly* to one of your batteries, with no bulb in the circuit, and measure the compass deflection for this "short circuit." Also try your other battery. The steel-cased batteries may strongly influence the compass, so measure the deflection by making and breaking the connection, without moving the battery or compass.

short circuit deflection, first battery:
short circuit deflection, second battery: the deflection is ~ 80°
5.3.3a

If the compass deflection with a short circuit is less than 45 degrees, you have a weak battery which should be replaced.

5.3.4 Length of a nichrome wire

❑ Nichrome is a metal alloy that is a conductor, but a rather poor one for a metal. Use two clip leads to connect the *thin* nichrome wire to two batteries in series (no bulbs). *Cautiously* feel the nichrome wire as you make the effective length longer or shorter by sliding one of the clip leads along the wire. *The wire can get quite hot, so be careful not to burn your fingers!*

Do you get a higher temperature with a shorter or with a longer length of nichrome wire? Also measure the current with your compass.

higher temperature with	shorter length or	longer length?
compass deflection with	shorter length = 40 °	longer length = 40 °
		5.3.4a ☆

equal

5.3.5 Thickness of a nichrome wire

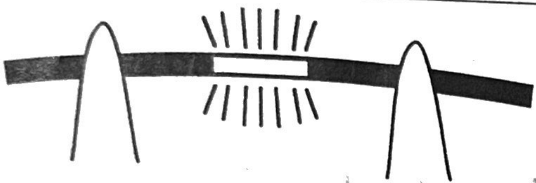
❑ Use two clip leads to connect the *thick* nichrome wire to two batteries in series (no bulbs). Choose the same length as you used for the long length of thin wire in the previous experiment.

compass deflection with thick wire and longer length = 40 °
For equal lengths, which circuit has the larger current? thin **thick**
5.3.5a ☆

This is related to your observations of the round bulb and long bulb. The filaments in the two bulbs are roughly the same length, but the filament in the round bulb is thicker, and we find that the current in the thick bulb is larger.

❑ **A glowing wire:** Use a *thin* nichrome wire. Move the clips closer and closer together until you see the center region of the nichrome wire glow. (You may need more batteries in series or a dark room to see the glow.)

Can you explain why there are non-glowing sections on either side of the glowing region? Surely there is current going through those parts of the wire, too?



the heat is difusing into the metal clamps which prevent a buildup enough to "glow"

5.3.5b ☆

Nichrome wire is used in toasters, where enough current is run through the wires to make them glow dully, but not nearly as bright as the tungsten filament in a light bulb (which is so hot it would burn up if exposed to air).

5.3.6 Summary: Current in different simple circuits

Electron current in various circuits. Summarize your data for the amount of electron current you found in each of these two-battery circuits, as measured by the compass deflection in degrees:

round bulb: 20°	long bulb: 20°
short, thin nichrome wire: 45°	long, thin nichrome wire: 60°
long, thick nichrome wire: 70°	short circuit, one battery : (should be > 45°) 90°
	5.3.6a ☆

We see that the amount of current

- is not the same in different circuits but depends on what we connect to the batteries;
- is larger with thicker wires;
- is smaller with longer wires; and
- is larger with two batteries in series than one (earlier measurement based on brightness).

5.3.7 What must be explained? Two puzzles

the resistence in wire is so low it is almost negligable

1) Where are the charges that create the electric field in the wires?

There must be a nonzero electric field inside the wires to make current flow in the circuit. If we make the reasonable assumption that the electric field in the wires is created by charges in or on the batteries, then adding long copper wires to the circuit, or twisting them into different configurations, ought to change the amount of current in the circuit. But the current doesn't change when we do this. Why? the electrons are simply being moved over. they do not have to travel the whole distance.

2) What do batteries do?

We might expect that the amount of current would be determined by the battery, yet we get different amounts of current out of the battery, depending on what we connect to the battery. But how does the battery "know" how much current it should put out?

So what is it that batteries do? And how do these circuits actually work? We will resolve these questions in Chapter 6. Before doing that, we need to look in more detail at how the current is distributed in various parts of a circuit.

5.4 Current in different parts of a circuit

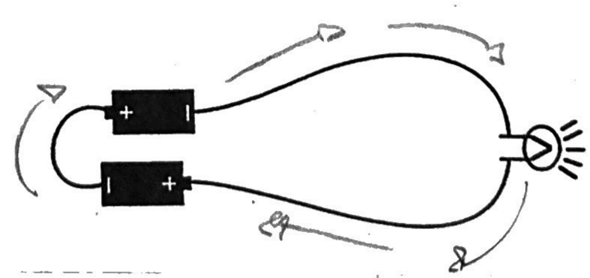
Is the current in different parts of a circuit the same, or different? Does it depend on the exact geometry of the circuit? In this section we will look into these questions.

5.4.1 A single bulb

Three students were arguing about the current in a circuit made up of two batteries and a bulb. Pat claimed that there is the same number of electrons per second passing any location around the circuit, but Leslie argued that since the electrons are used up in the bulb, there can't be any current coming out of the bulb. Robin disagreed with both of them, saying that not all of the electrons are converted into light, and the rest of the electrons come out the other side of the bulb, so there is *less* current but not zero.

Which student do you agree with? Or if you don't agree with any of them, briefly state your own view. It's fine to just guess! You'll have an opportunity in a moment to check your guess. Show your prediction on the sketch below. Indicate with arrows any places in the circuit where you think there is a current of flowing electrons. Draw the arrows in the directions that you think that electrons flow, without making any actual measurements. *Indicate the relative amounts of current in each wire.* Your sketch should agree with your answer to the previous question (or modify your previous answer to agree with your sketch).

Prediction:

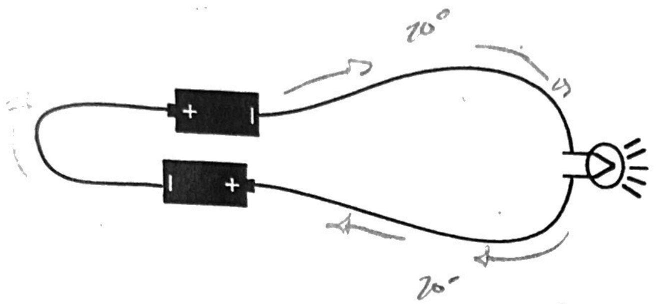


5.4.1a

❑ Now check your hypothesis in an actual circuit containing a round bulb (in order to get plenty of current). Using the compass as a detector, check every wire in the circuit to see how much current there is, and its direction. *Measure the compass deflection angles carefully, and record them on the diagram. Keep the batteries away from the compass (use long wires if necessary).* Check several places along the wire. ***Make sure you apply the following sensitive test: You can tell whether two currents are equal or not by running them side-by-side in opposite directions over the compass -- if the currents are equal, their effects will cancel each other and give zero deflection.***

Make a new sketch showing your experimental results in the same form as in the previous sketch, and comment on any discrepancies from the predictions you made. *Be sure to record deflection angles.*

Experimental observations:



5.4.1b ☆

This is an *extremely* crucial experiment.
Be sure to check your results with other groups and with your instructor!

On the basis of your observations, write a helpful comment explaining the physics to each of the students (Pat, Leslie, and Robin). Try to help them see why their prediction might have gone wrong.

Pat: a system will have one v_d throughout. so the deflection will be the same

Leslie: If no electrons came out it would take an ~~[illegible]~~ amount of electrons to light the bulb. Conservation of matter.

Robin: If this is the case, the bulb would slowly dim. Conservation of matter.

5.4.1c ☆

It is quite possible that Leslie and Robin still feel uneasy about all this. They might ask, "If electrons don't get used up in the bulb, what makes the light that we see?"

❑ Try this: Rub your hands together as hard as you can and as fast as you can for several seconds.

Your hands get hot. Do your hands get used up? Do you end up with fewer hands than you started with? What *does* get used up? Could you keep this up for a year, non-stop without eating?

Potential energy gets used up. So eventually, the supply will be depleted.

5.4.1d

In your circuit the bulb gets hot. Do the electrons get used up? Do you end up with fewer electrons than you started with? What *does* get used up? Could you keep this up for a year, non-stop without changing the battery?

the electrons get excited no used up. the potential energy goes used up. The battery will go out.

5.4.1e ☆

Forcing electrons through the filament heats the metal with a kind of friction, not unlike the friction that heats your hands when you rub them. In both cases chemical energy is converted into heat, but without using up the objects that rub against each other.

Remember the principle of charge conservation. What would happen to the bulb if more current entered the bulb than left the bulb, and this went on for a few seconds? (Later we'll see that more than 10^{18} electrons enter the bulb every second! See section 5.5.3.)

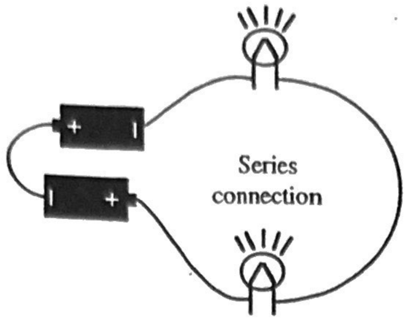
The filament would blow.

5.4.1f ☆

5.4.2 Currents in series circuits

You have shown that current is conserved in a circuit containing a single bulb. Let's look at what happens in a circuit containing two or more bulbs, connected in series (one after the other).

☐ Connect two round bulbs "in series" (one after the other around the circuit):



☐ Unscrew one of the two bulbs.

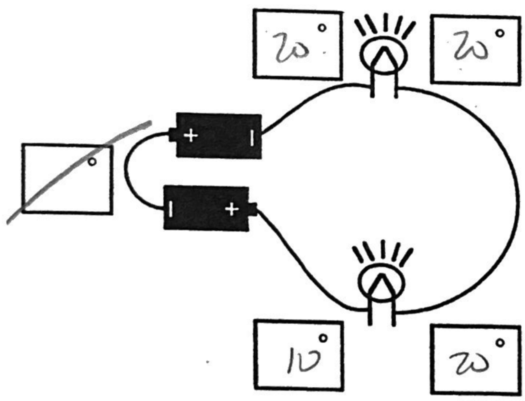
What happens to the other bulb? Why?

The other will turn off because the series is not closed. The other relies on the bulb to close the system.

5.4.2a

☐ **Current at different locations in a series circuit:** In the two-bulb circuit, use your compass to measure the amount of current at all locations of the circuit. *Be sure to measure the compass deflection angles carefully and record the angles in the boxes.*

In each box record the compass deflection you observe, in degrees, and explain briefly:



5.4.2b ☆

Compare the current in this two-bulb circuit with the current in a one-bulb circuit:

bulb in two-bulb circuit is **BRIGHTER** or **DIMMER** than in one-bulb circuit

$$\frac{\text{compass deflection in 2 - bulb circuit}}{\text{compass deflection in 1 - bulb circuit}} = \frac{20}{30} = \frac{2}{3}$$

5.4.2c ☆

We see again that the current coming out of the battery depends on what is connected to it.

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Many bulbs in series

did not do w/ physical bulbs

❑ If you can, work with other groups in order to try three, four, or more bulbs in series, until eventually you find that none of the bulbs glows.

Can you guess an explanation for this? Is there any current running through these bulbs? Can you detect any current with your compass?

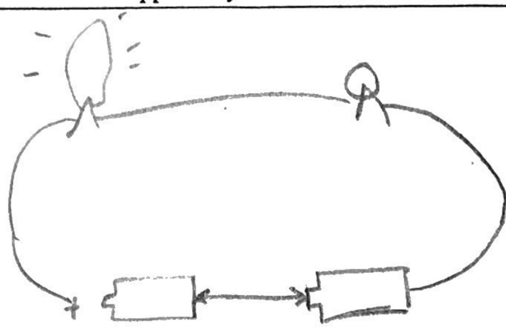
There is a current running through but with so much resistance that it isn't enough to heat the filament.

5.4.2d ☆

Round bulb and long bulb in series

❑ Here's a puzzle. Connect one round bulb and one long bulb in series, and you'll see something rather odd.

What did you observe? What happens if you unscrew the round bulb?



if you unscrew the round bulb the long bulb barely gets brighter

5.4.2e

This is an intriguing puzzle. It will be a while before we can fully explain what's going on, but we will eventually have a way to understand this.

☐ **Unscrew one of the two bulbs.**

What happens to the other bulb? Why?

the other bulb goes out. The socket relies on the bulb to close the circuit.

5.4.3a